# Lai,Yen-Huei

- **<u>Research areas</u>**
  - Bulk metallic glasses (BMG)
  - Microscale mechanical behaviors on BMG
  - Room and high temperature microcompression test

- **<u>Interesting topic</u>**
  - Effects of sample size on Mg- and Zr-based metallic glass micropillars in microcompression.
  - Homogeneous deformation of Au-based metallic glass micropillars in compression at elevated temperature.

- **Publications**
  - X. H. Du, J. C. Huang, K. C. Hsieh, J. S. C. Jang, and P. K. Liaw, **Y. H. Lai** and H. M. Chen, *"Two-Glassy-Phase Bulk Metallic Glass with Remarkable Plasticity"*, Appl. Phys. Lett., vol. 91, 131901 (2007).
  - **Y. H. Lai**, C. J. Lee, Y. T. Cheng, H. M. Chen, H. S. Chou, X. H. Du, C. I. Chang, J. C. Huang, S. R. Jain, J. S. C. Jang and T. G. Nieh, *"Bulk and Microscale Compressive Properties of Zr-Based Metallic Glass"*, Scr. Mater. 58, 890 (2008).
  - S. X. Song, **Y. H. Lai**, J. C. Huang and T. G. Nieh, "*Homogeneous deformation of Au-based metallic glass micropillars in compression at elevated temperature*" Appl. Phys. Lett., vol. 94, 061911 (2009).

# 以微米壓縮測試量測鎂基與鋯基金屬玻璃微米柱之尺寸效應

# Effects of Sample Size on Mg- and Zr-Based Metallic Glass Micropillars in Microcompression


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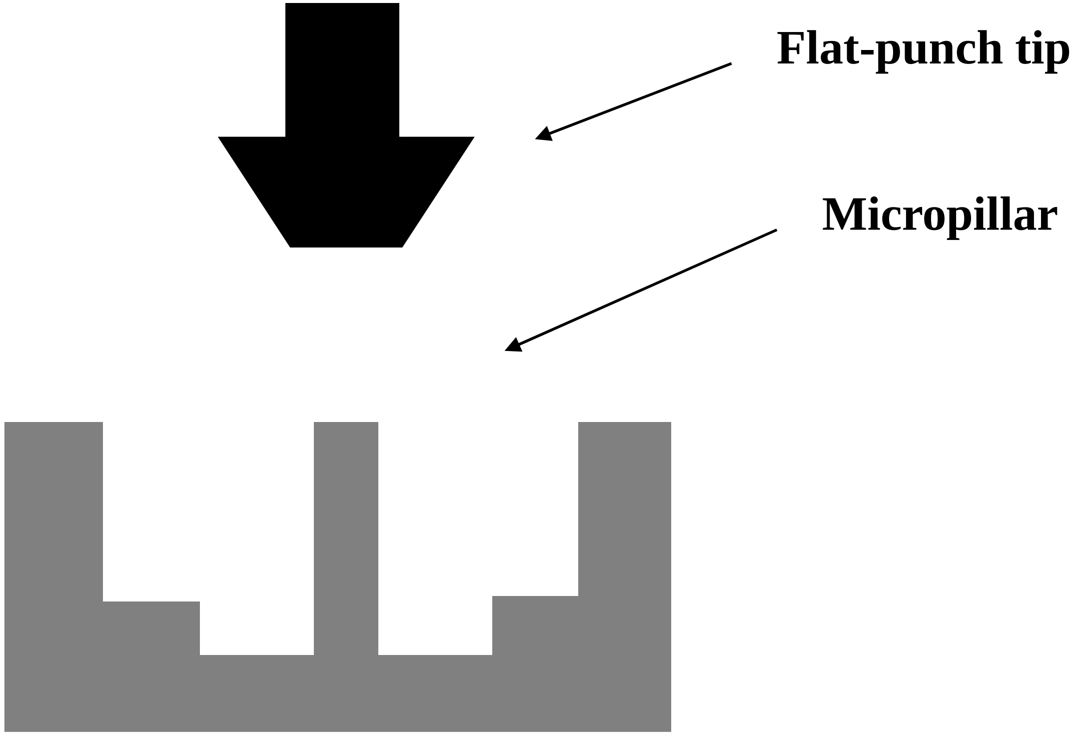
***Department of Materials and Optoelectronic Science***

# What is microcompression test?

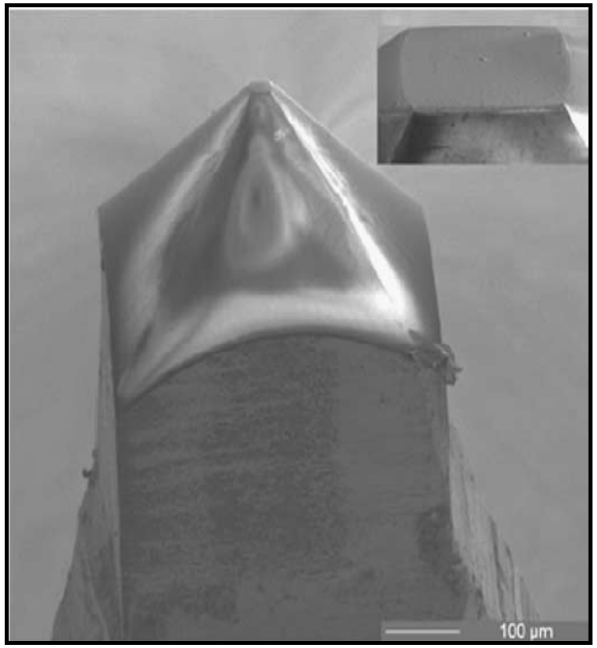
- This technique, developed by Uchic et al. in 2004, was first applied to examine the mechanical properties of micrometer sized sample.

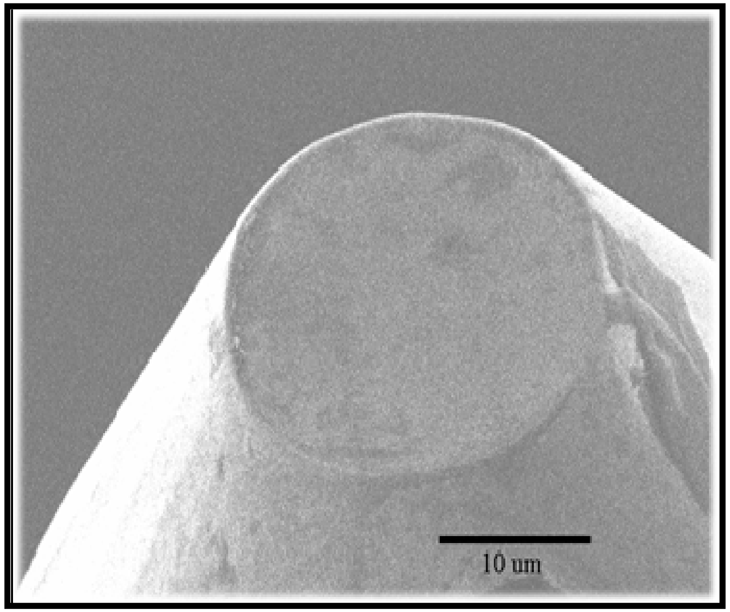



M. D. Uchic, D. M. Dimidux, J. N. Florando and W. D. Nix, Science, 2004, 305, 986-989.

# Flat-punch tip

- Utilizing the focus ion beam (FIB) to machine the flat-punch diamond indentation tip.

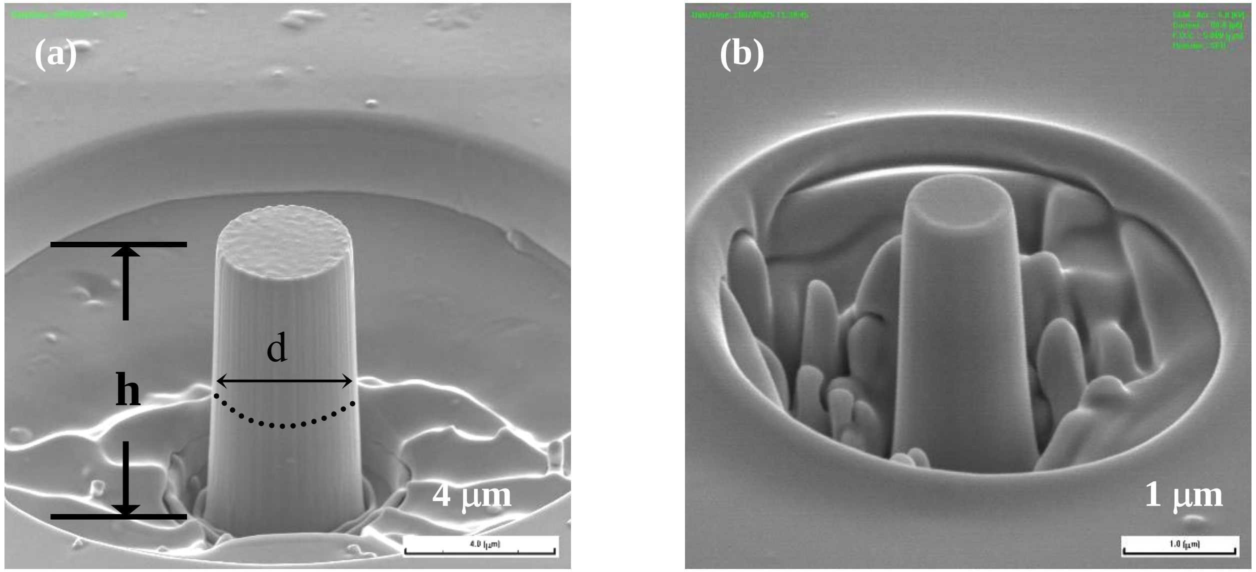



D. M. Dimiduk, M. D. Uchic and T. A. Parthasarathy, Acta Mater., 53 (2005), 4065-4077.

# Micropillar

- For Mg-based BMG



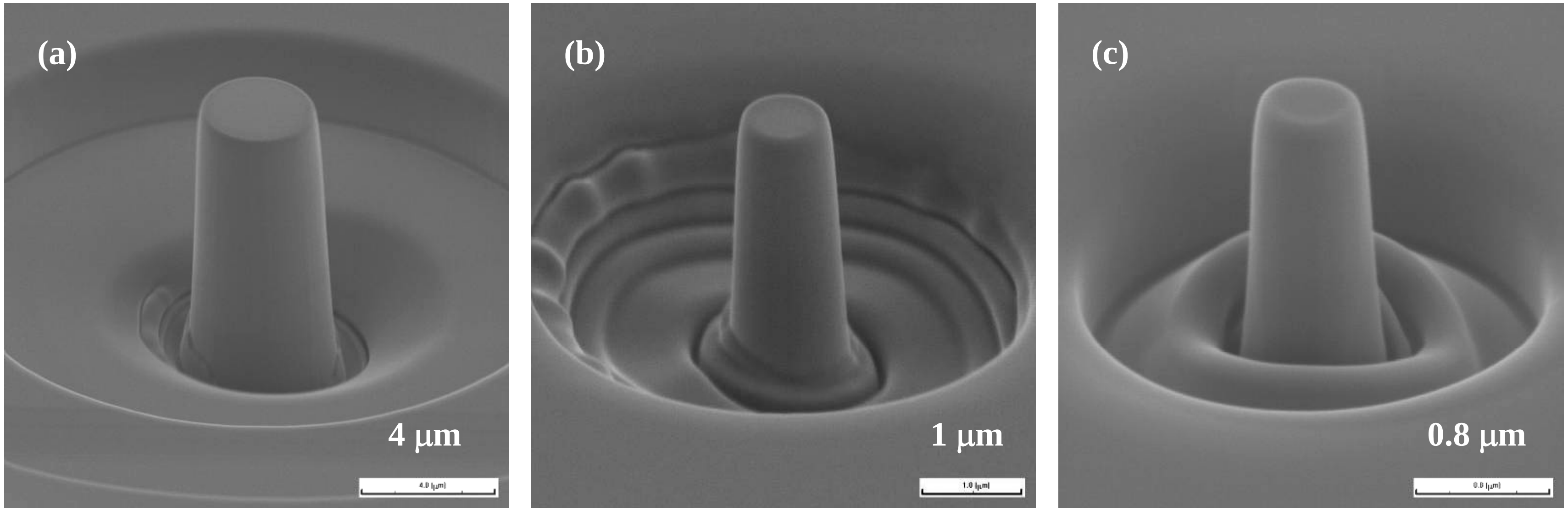

d ~ 3.8 µm, h ~ 8.5 µm

d ~ 1 µm, h ~ 2.5 µm

SEM micrographs of pillars for the Mg-based BMG before microcompression test.

# Micropillar

- For Zr-based BMG




**d ~ 3.8 μm, h ~ 8.5 μm** **d ~ 1 μm, h ~ 2.5 μm** **d ~ 700 nm, h ~ 1.6 μm**

SEM micrographs of pillars for the Mg-based BMG before microcompression test.

# Research motive

**Bulk metallic glasses possess several outstanding properties that make them desirable structural materials for micro-electro-mechanical system (MEMS) devices.**

**What are the characteristics of the fundamental mechanical properties of micro-sized BMGs?**

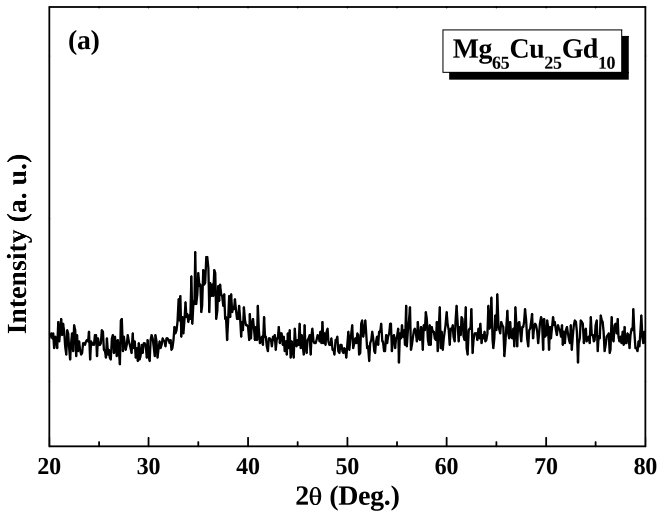
**The development of microcompression test is critical to measure microscale mechanical properties.**

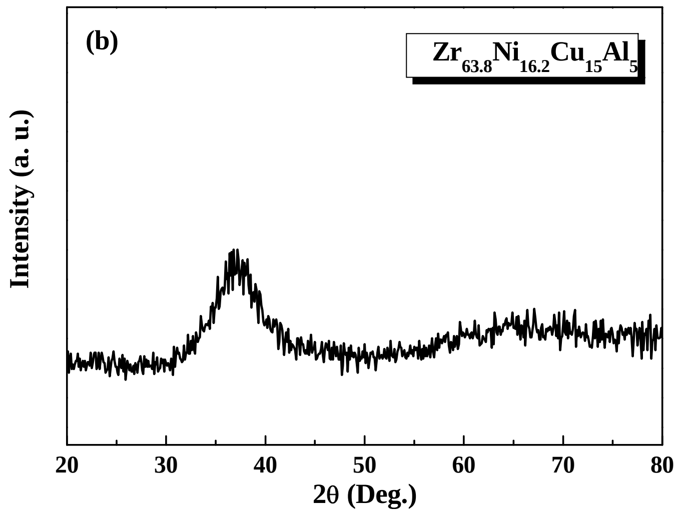
**Another purpose of this study is to gain the intrinsic yield strength by using microcompression test.**

# Preliminary results

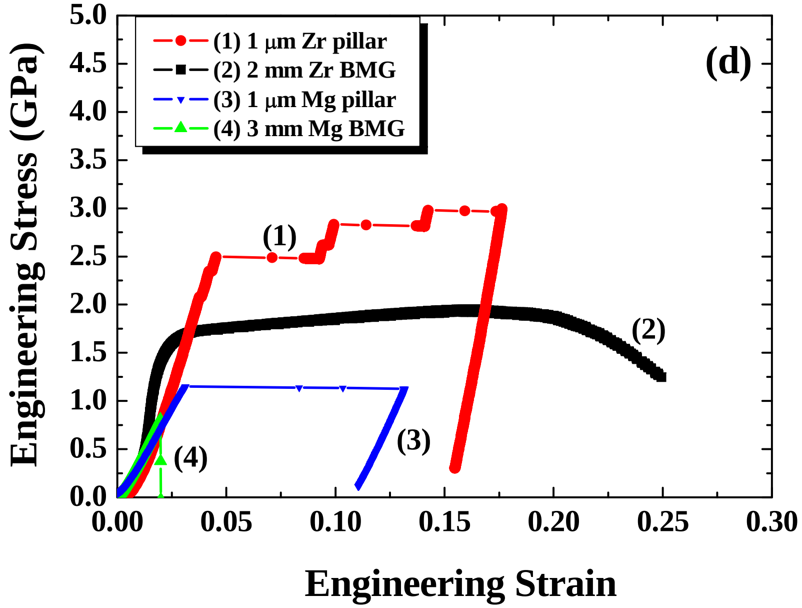
- **Materials**
  - $Mg_{65}Cu_{25}Gd_{10}$ (the Mg-based BMG)
  - $Zr_{63.8}Ni_{16.2}Cu_{15}Al_{5}$ (the Zr-based BMG)

- **X-ray diffraction analysis**

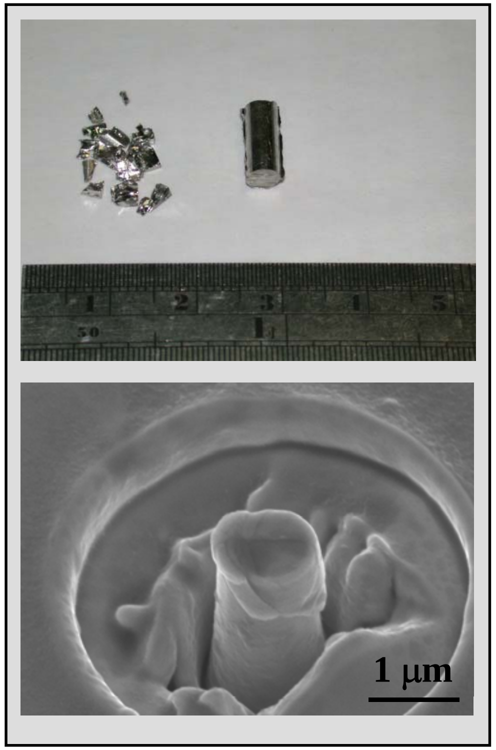


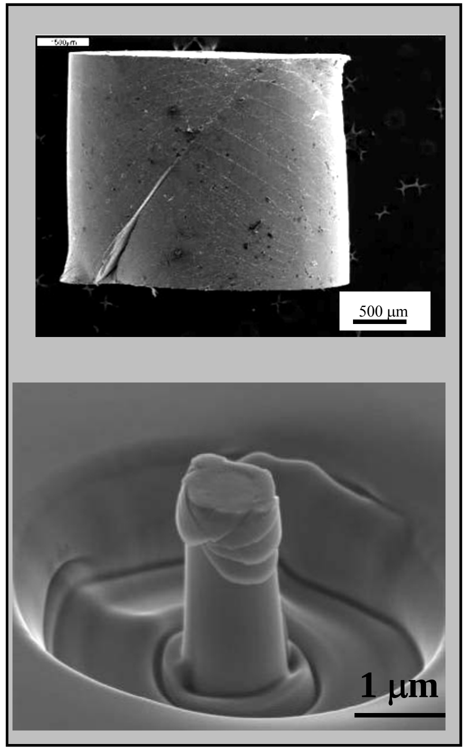
# Comparison between the bulks and micropillars




**Mg-based BMG**




**Zr-based BMG**




The comparison of the curves for the Zr- and Mg-based bulk compression samples, and the 1 μm Zr- and Mg-based micropillars, compressed at the strain rate of $10^{-4}$ $s^{-1}$.

# Homogeneous Deformation of Au-based Metallic Glass Micropillars in Compression at Elevated Temperature

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# High-temperature microcompression test for the Au-based BMG

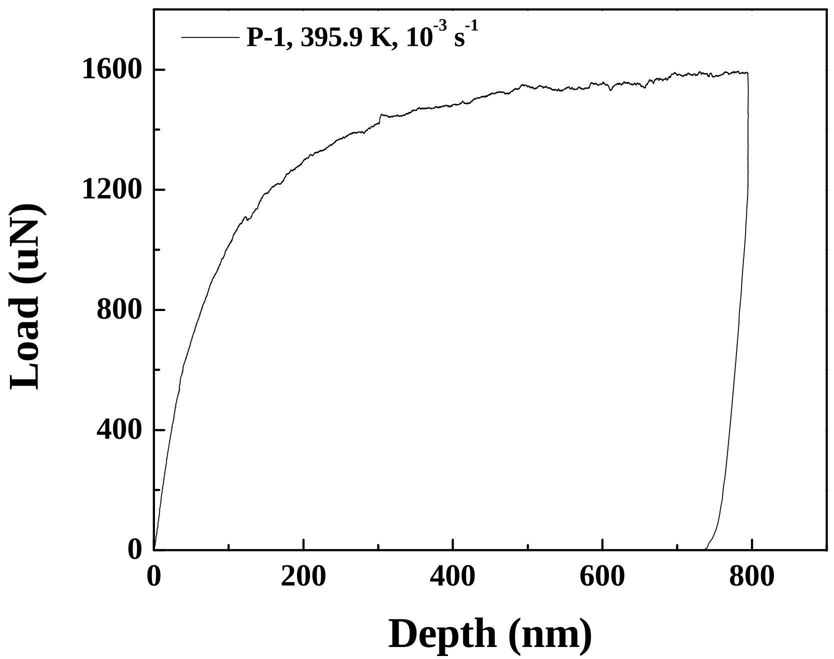
- Material: Au-based BMG ($Au_{49}Ag_{5.5}Pd_{2.3}Cu_{26.9}Si_{16.3}$)
- Pillar size: 3.8 μm
  - (a) High oxidation resistance at high temperature.
  - (b) Low glass transition temperature ($T_g$ = 401 K).

Table 1 Testing conditions for different pillars.

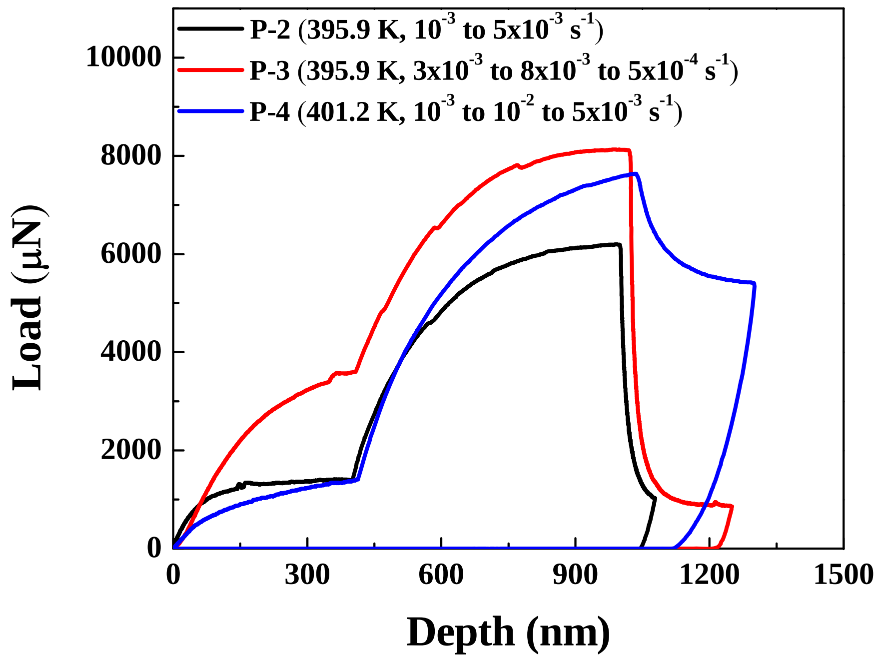
| Pillar | H (μm) | Temperature (K) | Nominal strain rate ($s^{-1}$) |
|---|---|---|---|
| P-1 | 8.762 | 395.9 | $10^{-3}$ |
| P-2 | 8.794 | 395.9 | $10^{-3}$ to $5x10^{-3}$ to $5x10^{-4}$ |
| P-3 | 8.885 | 395.9 | $3x10^{-3}$ to $8x10^{-3}$ to $5x10^{-4}$ |
| P-4 | 9.010 | 401.2 | $10^{-3}$ to $10^{-2}$ to $5x10^{-3}$ |

# Load-displacement curves

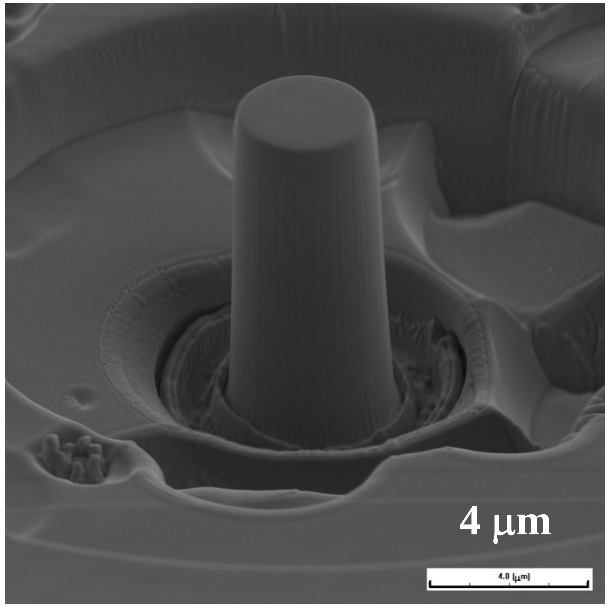
(a) Constant strain rate test

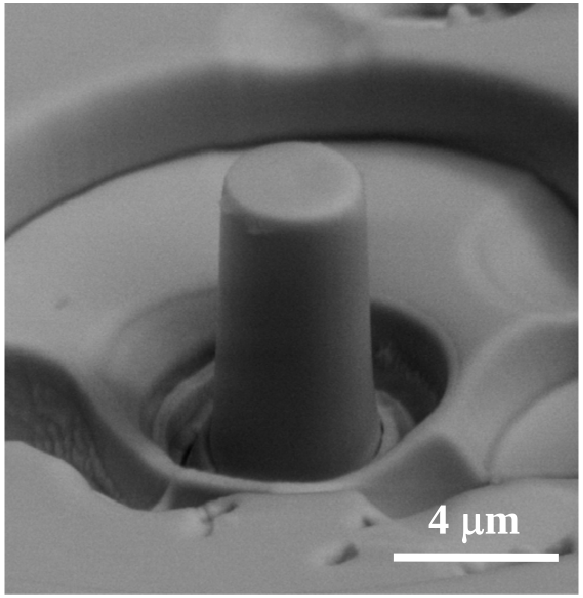



(b) Strain rate change test



# SEM micrographs after compression



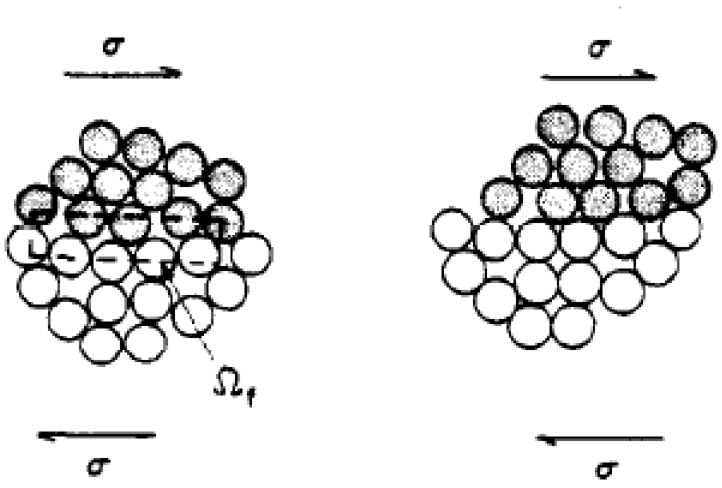




| | $H_1$ (μm) | $H_2$ (μm) | ΔH (μm) | ΔL (μm) | t (sec) | \|ΔH-ΔL\|/t (nm/s) | Drift rate (nm/s) |
|---|---|---|---|---|---|---|---|
| P-1 | 8.762 | 7.936 | 0.826 | 0.737 | 114 | 0.78 | 0.82 |
| P-2 | 8.794 | 7.789 | 1.005 | 1.045 | 97 | 0.41 | 0.22 |
| P-3 | 8.885 | 7.675 | 1.158 | 1.212 | 97 | 0.56 | 0.56 |
| P-4 | 9.010 | 7.812 | 1.198 | 1.126 | 79 | 0.91 | 0.76 |

- **The high-temperature microcompression technique is reliable**

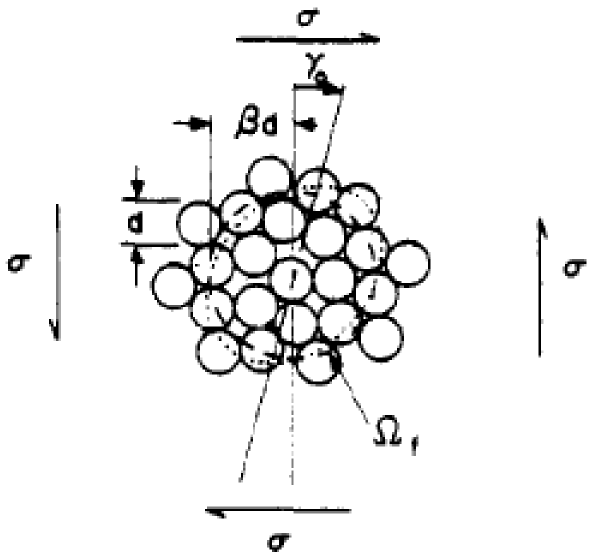
# STZ model

(a) At low temperature ($0 < T < 0.6T_g$)




**A narrow disk shaped region**

(b) At high temperature ($0.6\ T_g < T < T_g$)




**A roughly spherical region**

A. S. Argon, Acta Metall. **27**, 47 (1979)

# STZ model

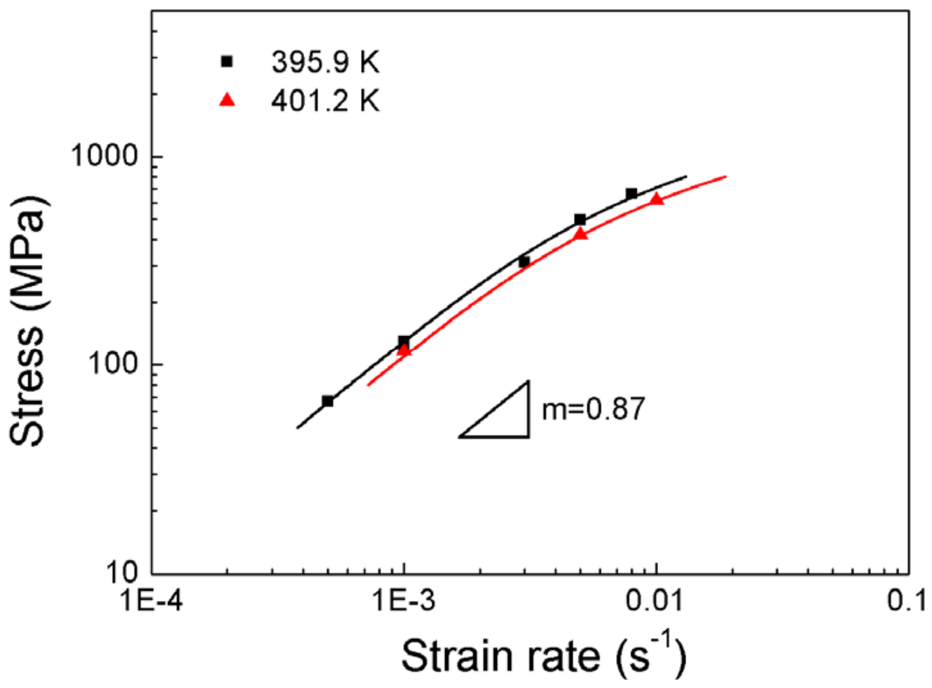
- Based upon a STZ model, the strain rate during homogeneous deformation of BMG can be described by

$$\dot{\varepsilon} = \alpha \varepsilon_o v_G \exp(-\frac{\Delta F}{kT}) \sinh(\frac{\sigma V}{2\sqrt{3}kT}) = \dot{\varepsilon}_T \sinh(\frac{\sigma V}{2\sqrt{3}kT})$$

Where $\dot{\varepsilon}_T$ is a temperature-dependent rate constant, $k$ is Boltzmann's constant and $T$ is the temperature, $V$ is the activation volume ($V=v_0\varepsilon_0$, in which $v_0$ is the volume of a flow unit or STZ and it undergo a strain $\varepsilon_0$ (~0.125) during deformation).

A. S. Argon and L. T. Shi, Acta Metall. **31**, 499 (1983)

# Activation volume




- Strain rate sensitivity (m) = 0.87
- Newtonian flow

**Activation volume**

| T (K) | $\dot{\varepsilon}_T$ (s$^{-1}$) | $V$ (Å$^3$) | $v_0$ (Å$^3$) |
|---|---|---|---|
| 395.9 | 0.0026 | 55 | 440 |
| 401.2 | 0.0027 | 62 | 496 |

**STZ volume**

Au-based BMG:

Density=13.72 g/cm$^3$
Atomic weight=126.5 g/mol
Average atomic volume=15.3 Å$^3$

- **STZ volume = 29 – 32 atoms**
- **Radius of STZ = 5 Å**

# Thanks for your attention!

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